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A PRELIMINARY INVESTIGATION OF THE HEAVY MINERAL SUITES OF THE COASTAL RIVERS AND BEACHES OF OREGON AND NORTHERN CALIFORNIA

By

By L. D. Kulm*, K. F. Scheidegger*,
J. V. Byrne*, and J. J. Spigai*

Introduction

Coastal rivers of Oregon, Washington, and northern California are the primary suppliers of sediments to the adjacent continental shelf, slope, and deep-sea environment. The Columbia River is the largest supplier of terrigenous materials to the entire northeastern Pacific Ocean. Silts and clays from the Columbia and the smaller coastal drainage areas are spread over large portions of the northeast Pacific. These fine-grained sediments account for a large volume of the marine deposits, but it is difficult to trace them to specific continental drainage basins. The sand portion of marine sediments, on the other hand, can be traced to continental sources with greater accuracy through heavy mineral assemblages, provided that it has not been extensively modified during or subsequent to transportation. Although the heavy minerals may reflect the general nature of the continental source rocks from which they were derived, the relative contribution of the sediment sources may be more accurately defined when the heavy mineral suite of individual drainage basins is known.

The sands of coastal rivers and beaches of Oregon and northern California, with some exceptions, are compositionally diverse and immature. The diversity and immaturity are reflected in the more than 30 heavy mineral species present; the large percentages of unstable minerals, such as hypersthene and augite (Pettijohn, 1957); and the low quartz/feldspar ratios and abundant lithic fragments (Kulm, 1965 and Whetten, 1966). These data suggest that most of the coastal sediments were derived from source areas characterized by high relief and rapid mechanical erosion. Such conditions do, in fact, exist in the coastal drainages of Oregon and northern California where rainfall and river runoff are high.

One of the objectives of the present study is to determine the nature

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* Department of Oceanography, Oregon State University, Corvallis, Ore.

of the heavy mineral suites in each of the major coastal drainages of Oregon and northern California that contribute sediment to the ocean. Once the heavy mineral suites of the beach sands and continental shelf and deep-sea sediments are defined, areal and temporal variations in sediment sources can be detected. With a knowledge of the heavy mineral suites in the river drainages, an attempt is made in this study to determine the predominant direction of littoral drift or sediment transport along the coast.

Sampling and Sediment Analysis

One sample was collected in each of the 26 major coastal rivers of Oregon and northern California; two were collected in the Columbia River. With the exception of the Columbia, samples were taken upstream of tidal influence to eliminate the effects of the intrusion of marine sediments. Sand-size sediments were taken at a number of sites, such as the channels, exposed sand bars, and adjacent river terraces, depending upon the accessibility of the deposit. An attempt was made to collect sediments in the fine and very fine sand class (Wentworth, 1922) in order to obtain the majority of the heavy mineral species present in each drainage basin. Five beach samples were selected for analysis from a total of 70 collected from the upper foreshore along the northern California and Oregon coast.

River sediments were sieved according to the size classes of Wentworth (1922). Three size classes (62-125, 125-250, and 250-500 microns) were chosen for heavy mineral identification and to determine if there was selective sorting of the mineral assemblage. For the beaches an unsized sand sample was used. A plot of the percentage of each of the major heavy mineral species against the median diameter of the total sediment shows that the heavy mineralogy of most sediments is not controlled by selective sorting.

The heavy mineral separation was made with tetrabromoethane (specific gravity 2.96). Magnetic minerals, chiefly magnetite and some ilmenite, were removed from the heavy mineral fraction and weighed. This fraction was examined to see if nonopaques were included; in some cases, small amounts of hypersthene with magnetic inclusions were removed. The heavy minerals were mounted in Canada balsam and identified with the aid of a petrographic microscope. At least 200 nonopaque, nonmicaceous grains were counted for each of the three size fractions. A 300-grain count was made for the beach samples. The combined heavy mineral assemblage of all three size classes of the rivers and the beach assemblages are given in table 1.

Heavy Mineralogy of Coastal Drainages

Heavy mineral suites of the major coastal rivers of Oregon and northern California can be conveniently discussed with respect to the continental watersheds defined by Hagenstein and others, 1966 (figure 1). The four basins include 1) the Klamath-South Coast Basins, 2) the Umpqua and Mid-Coast Basins, and 3) North Coast Basin, and 4) all basins drained by the Columbia River. Each of the watershed basins generally has a characteristic heavy mineral suite that distinguishes it from the adjacent basins.

The relative amount of sediment transported to the ocean from the various drainage basins can be determined by assuming a direct correlation between river runoff and sediment load. The annual freshwater discharge for the four drainage basins described above is shown in figure 1. Heavy mineral assemblages in these four drainage basins are given as the weighted averages of the mineral values for all the rivers sampled within a particular basin (table 2). The weighted average of a particular heavy mineral species in a basin is obtained by summing the products of river runoffs and their respective heavy mineral percentages and dividing this sum by the total runoff of all rivers in the basin. The runoff data for the rivers and basins were obtained from Lockett (1965), Hagenstein and others (1966), and the U.S. Geological Survey Surface Water Records for California (1964) and for Oregon (1966).

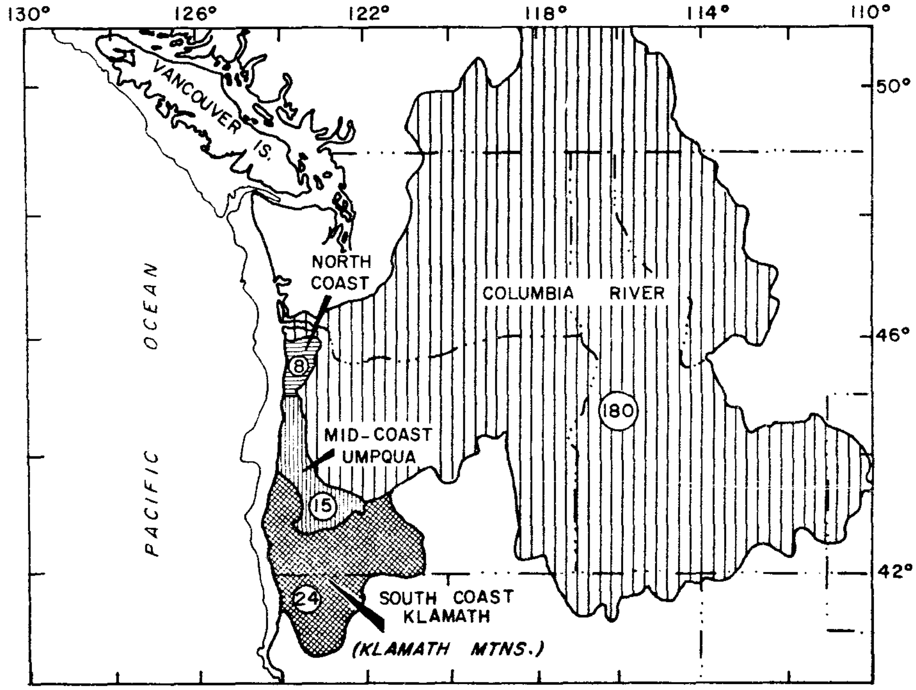

Figure 1. Continental drainage basins of northwestern United States. Circled numbers are approximate average annual runoff in millions of acre feet. (Modified from Duncan, 1968.)

TABLE 1

COMBINED HEAVY MINERAL COUNTS OF NON-OPAQUE GRAINS FOR COASTAL RIVERS AND BEACHES

Numbers are given in percent of total assemblage

Symbol "T" denotes mineral contents less than one percent

MINERAL	RIVER	Columbia	Necanicum	N. Fk. Nehalem	Nehalem	Miami	Kilchis	Wilson	Trask	Tillamook	Nestucca	Little Nestucca	Salmon	Siletz	Yaquina	Alsea	Siuslaw	Umpqua	Millicoma	Coos	Coquille	Sixes	Elk	Rogue	Pistol	Chetco	Smith	Klamath	BEACH	Arch Cape	Otter Rock	Yachats	Coquille	Cape Sebastian
Amphibole Group		28	4	4	3	T		T	T	1	1	T		2	18	9	18	25	34	31	28	47	66	75	15	37	42	76		18	26	24	53	57
Actinolite-Tremolite		1																2	T	1	4	1	16	6	3	3	7	4		6	3	2	14	21
Glaucophane																					1	8		T	2			T				1	4	6
Hornblende		27	4	4	3	T		T	T	1	1	T		2	18	9	18	23	33	30	23	38	50	69	10	34	35	72		12	23	21	35	30
Basaltic		4													1				3	1	T		T	1	1					T	2	4	1	2
Blue-Green		6																11	7	6	7	19	19	28	2	12	11	41		1	4	1	7	14
Brown		8		3	T	T			T	T	T	T		2		4	7	5	9	7	5	3	2	10		1	4	5		3	10	9	13	2
Green		9	4	1	3	T		T	T	T	T				17	5	11	7	14	16	11	16	29	30	7	21	20	26		8	7	7	14	12
Apatite												T			5	T	T	T							T			T		T	1	1	3	
Epidote Group		1	T												14	T	2	5	7	14	6	6	7	5	12	5	3	3		5	4	1	3	5
Clinozoisite		T																2	3	4	2		3	2	5	3	1	2						
Epidote		T	T												14	T	2	3	4	9	4	6	4	1	7	2	2	1						
Zoisite																				1				2				T						

Garnet Group	1			T			T		T					14	T	18	2	21	15	7	5	2		2	2		1	13	6	15	7	4
Clear	1			T			T									7	1	6	8	3	5	1			1		1	1	1	2		
Pink	T								T						T	11	1	14	7	4		1		2	1		T	8	3	10	5	2
Salmon																T		1										4	2	3	2	2
Kyanite	T																											3			T	T
Monazite														4															T	T	T	
Olivine Group	2			2	T	2	T	1	1	1	1		1				T		T		1	1	2		4	28	T	2	1	1	2	2
Pyroxene Group	64	93	94	92	97	98	97	98	96	98	97	100	97	29	88	46	64	23	28	49	30	19	17	55	44	21	12	43	43	35	18	12
Orthopyroxenes	36	4	2	5	T				T	2	T	T	T	1	T	2	22	1	2	3	4	2	5	5	5	3	3	4	12	8	7	8
Enstatite	T	T	T	T						T					T		T	T	T					4	1	1	1	1	2	2	3	2
Hypersthene	36	3	2	4	T				T	2	T	T	T	1		2	21	1	2	3	4	2	5	1	4	2	2	3	10	6	4	6
Clinopyroxenes	28	89	92	87	97	98	97	98	96	96	96	100	97	28	88	44	42	22	26	46	26	17	12	50	39	18	9	39	31	27	11	4
Augite + Diopside	28	86	89	87	97	98	95	92	95	86	92	95	89	28	87	43	42	22	26	46	25	17	12	50	39	18	9					
Titanaugite	T	3	3	T			2	6	1	10	4	5	8		1	1			T		1											
Rutile															T	3	T	2	T	2	1	T			T		1		1	3	4	2
Sillimanite	T																					T										
Sphene														5		2	T	2	1	T					T			6	3	3	1	2
Spinel																	T										T		T		1	
Staurolite																	T	T	T				T	T				2	2	4	T	2
Topaz																													T			
Tourmaline	T		T												T	T		T	T				T	T			T		T	1		5
Zircon				T			T				T			7	T	9	1	6	5	3	1	2		13	4	T		4	1	3	4	2
Other Minerals + Unknowns	4	3	2	3	3		3	1	2		2			4	3	2	2	5	6	5	9	3	1	3	4	6	7	4	12	9	4	7

TABLE 2

HEAVY MINERAL SUITES FOR THE MAJOR COASTAL DRAINAGES

Percentages are based on weighted averages

Note pyroxene/amphibole ratios at the bottom of the table

Mineral	Columbia River Basin	North Coast Basin	Umpqua and Mid-Coast Basins	Klamath-South Coast Basins
AMPHIBOLE GROUP	28	2	20	65
Actinolite and Tremolite	1	--	1	5
Glaucophane	--	--	--	1
Hornblende	27	2	19	59
Blue-Green	6	--	6	29
Brown + Green + Basaltic	21	2	13	30
EPIDOTE GROUP	1	--	4	4
GARNET GROUP	2	--	5	2
OLIVINE GROUP	2	1	1	4
PYROXENE GROUP	64	96	61	19
Orthopyroxenes	36	1	14	3
Clinopyroxenes	28	95	47	16
Augite + Diopside	27	91	47	16
Titanaugite	1	4	--	--
OTHER MINERALS	3	1	9	6
Pyroxene/Amphibole Ratios				
Weighted Average	2.3	48.0	3.1	0.3

Klamath-South Coast Basins

The Klamath and Smith Rivers of northern California and the Chetco, Pistol, Rogue, Elk, Sixes, Coquille, Coos, and Millicoma Rivers of southern Oregon make up the Klamath-South Coast Basins. Two of these rivers, the Klamath and Rogue, have a combined drainage area of 20,775 square miles (84 percent of the total land area of the basins) and have an average annual yield of 21.5 million acre feet (68 percent of the total average annual yield of the drainage).

The Klamath-South Coast Basins are characterized by an amphibole assemblage which consists principally of blue-green and green hornblende, with lesser amounts of actinolite-tremolite. This suite of heavy minerals is present in all of the rivers of the Klamath-South Coast Basins and only in the Coquille, Pistol, and Chetco Rivers is the pyroxene group quantitatively larger than the amphibole group. The pyroxene/amphibole ratio (based on weighted averages) is 0.3 for these basins. One-half of the southern drainage basins, including the Klamath and Rogue, contain minor amounts of glaucophane. Although present in small amounts, glaucophane is a diagnostically important mineral because it appears only in these drainages. Epidote and clinozoisite-zoisite also occur in virtually all of these drainages, but are not restricted to them. The Smith River of northern California is unique because it contains a substantial amount of olivine. In addition, unusually high percentages of garnet are present in the Coos and Millicoma Rivers. The combined heavy mineral assemblage of blue-green hornblende, actinolite-tremolite, glaucophane and the epidote group show the strong metamorphic character of the source rocks in the Klamath-South Coast Basins.

The Klamath and Rogue Rivers have their headwaters in the Pliocene and Recent lava flows of the High Cascades to the east and flow westward across the Klamath Mountains of southwestern Oregon and northwestern California. Paleozoic and Mesozoic metasedimentary, metavolcanic, and sedimentary rocks of the Klamath Mountains, which have been intruded by granitoid and ultrabasic rocks (Baldwin, 1964), are probably responsible for the distinctive mineralogy. According to Irwin (1960), the metamorphic grade of the Abrams and Salmon Formations of the central metamorphic belt of the Klamath Mountains is the almandine zone of the regional, greenschist facies as defined by Barrow and Tilley for the Scottish Highlands. Typical minerals of this facies include: epidote, tremolite, hornblende, and almandine (Turner and Verhoogen, 1960). Glaucophane is derived from glaucophane-bearing schists of the Franciscan Formation of northern California and the Dothan (?) Formation of Oregon (Irwin, 1960). According to Taliaferro (1943) the glaucophane and related schists are the result of pneumatolytic metamorphism by the emanations accompanying the intrusion of mafic and ultramafic rocks. If this origin is correct, this could account for the patchiness of the glaucophane distribution in the rivers.

Along the coast the Smith, Chetco, Pistol, Elk, Sixes, Coquille, Coos, and Millicoma Rivers drain the western slopes of the Klamath Mountains and the Miocene-Pliocene and Quaternary marine formations of the southern end of the Oregon Coast Range.

Umpqua and Mid-Coast Basins

The Umpqua, Siuslaw, Alsea, Yaquina, Siletz, and Salmon Rivers comprise the Umpqua and Mid-Coast Basins. Seventy-two percent of the drainage area and 51 percent of the river discharge are associated with the Umpqua River. It drains the northern tip of the Klamath Mountains and a segment of the Cascade Mountains on the eastern border of the basin, but the largest portion of the basin is located in the southern Oregon Coast Range.

A diverse heavy mineral assemblage occurs in the Umpqua, Siuslaw, Alsea, and Yaquina drainages. Although the Siletz and Salmon Rivers are part of the Mid-Coast Basins, their heavy mineral suite is similar to that of the North Coast Basin and they will be discussed in the following section. The Umpqua River sediments are dominated by pyroxenes which account for 64 percent of the heavy mineral suite; hypersthene makes up one-third of this assemblage, which is the highest percentage found in any of the coastal rivers of Oregon except the Columbia River to the north. The rather high hypersthene content of the Umpqua River may be associated with sources in the Cascade Mountains. Glenn (1965) reported that hypersthene is abundant in sediments derived from the Cascade Mountains. Blue-green hornblende and actinolite-tremolite which are typical of the rivers to the south are also present in the Umpqua River, but in smaller quantities. The metamorphic minerals were probably derived from that portion of the Umpqua drainage which includes the northern part of the Klamath Mountains. Glaucophane appears to be absent in this drainage.

To the north the Siuslaw, Alsea, and Yaquina Rivers are characterized by a pyroxene assemblage, but with only minor amounts of hypersthene. High percentages of garnet have replaced blue-green hornblende in these drainages. As in the Umpqua, green and brown hornblende generally account for more than 10 percent of the heavy mineral suite. In the Umpqua and Mid-Coast Basins the weighted average for the pyroxene/amphibole ratio is 3.1.

Most of the rocks in the southern Coast Range are composed of volcanic materials, largely basalt, and Eocene sedimentary rocks (Baldwin, 1964).

North Coast Basin

The North Coast Basin includes all of those rivers from the Salmon to the Necanicum. Based on drainage area and river runoff, the North Coast Basin contributes the smallest quantity of sediment to the ocean of all the basins examined.

The North Coast Basin is characterized by a heavy mineral assemblage consisting almost entirely of clinopyroxenes and a high pyroxene/amphibole ratio (48.0). This assemblage also occurs in the Siletz and Salmon Rivers, which are considered to be a part of the Mid-Coast drainage basin (Hagenstein and others, 1966). Minor heavy mineral constituents in this basin include green and brown hornblende and olivine. Titanaugite occurs in all but two of the rivers. Although titanaugite occurs in small quantities, it appears to be a diagnostically important mineral for the North Coast Basin. Snavely, Wagner and MacLeod (1965) noted that titaniferous augite is quite common in the basalt flows and breccias of the central Oregon Coast

Range.

Basic igneous rocks (principally basalt) and marine sedimentary rocks, derived from the weathering and erosion of basic igneous rocks, appear to be the source for the relatively simple heavy mineral suites of the rivers in the North Coast Basin. Thick submarine volcanic flows, breccias, and tuffaceous sedimentary rocks of the early Eocene Siletz River Volcanics constitute most of the central core of the Coast Range in this basin (Baldwin, 1964). The Tyee Formation, the most widespread formation in the Coast Range, extends as far north as Hebo, Oregon, and is composed of massive arkosic and micaceous sandstones and sandy siltstones (Baldwin, 1964). The small percentages of metamorphic minerals that are found in the Alsea and Yaquina Rivers were probably derived from the weathering of the Tyee sandstones in the central Coast Range (Kulm, 1962).

Columbia River Basin

The Columbia River has the third largest drainage of all rivers in the United States (Highsmith, 1962), and drains an area of approximately 259,000 square miles. It originates in the Canadian Rockies and flows south and west 1200 miles to the Pacific Ocean, where it discharges annually approximately 180 million acre feet of water (Lockett, 1965). The Columbia River transports annually approximately 14,500,000 cubic yards of suspended sediment (U.S. Army Engineers, 1962). Lockett (1965) reports a bedload of 1,780,000 cubic yards measured at Vancouver, Wash. When the drainage area and annual flow of this river are compared with that of the other drainage basins discussed, it is obvious that the sediment discharge of this river should dominate the terrigenous sediments of the adjoining marine environment.

In the lower channel of the Columbia River the heavy mineral assemblage consists mainly of pyroxene; hypersthene accounts for more than one-half of this assemblage. Glenn (1965) also found large percentages of hypersthene in the tributaries of the Willamette River which drain portions of the Cascade Mountains and eventually empty into the Columbia. According to Glenn, the Cascade Mountains' heavy mineral suite is characterized by large percentages of augite and hypersthene. Continental shelf surface sediments directly off the mouth of the Columbia also contain abundant hypersthene (Runge, 1966). Hornblende, including the blue-green variety, is prominent in the Columbia heavy mineral suite, while epidote, garnet, and olivine appear to be minor constituents. Many other mineral species are also present but occur in only trace amounts. The blue-green hornblende in the Columbia River sediments does not appear to be nearly as abundant as it is in the Klamath-South Coast Basins. Our limited heavy mineral analyses as well as those of Glenn (1965) show that glaucophane is absent in the Columbia River. Studies of the adjacent marine environments (Runge, 1966; Carlson, 1967; Nelson, 1968; and Duncan, 1968) which

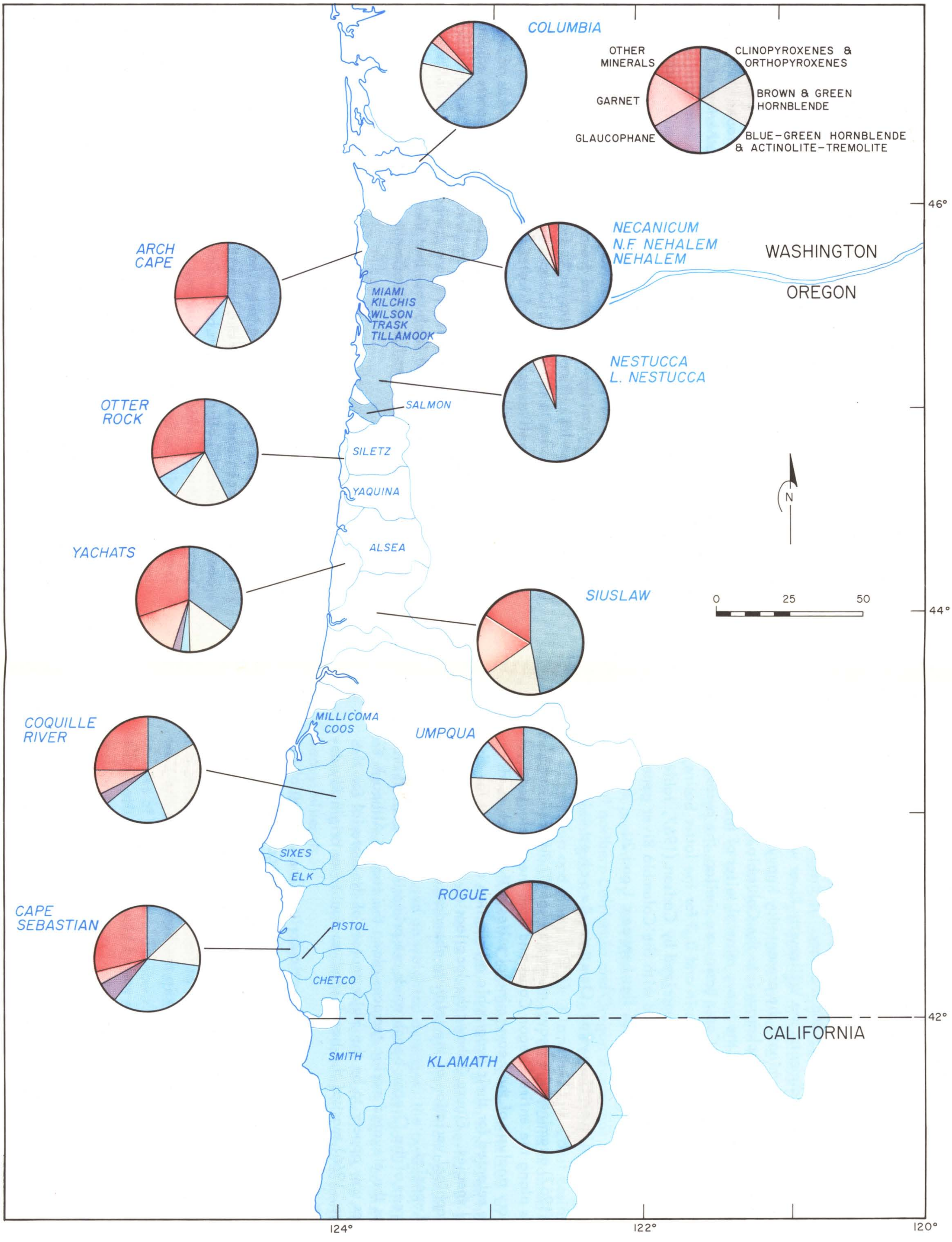

Figure 2. Typical heavy mineral suites of coastal drainages and beaches of northern California and Oregon. See Figure 1 for geographic distribution of continental watersheds.

receive sediments from the Columbia River also show that glacophane is absent. It appears that glacophane occurs only in the Klamath-South Coast Basins and, when present, it is a diagnostic indicator of the sediments in these basins.

Whetten (1965) indicates that clinopyroxenes are quantitatively equal to or greater than the orthopyroxenes in three downstream Columbia River reservoirs - Bonneville, The Dalles, and McNary. If these reservoirs tend to trap the coarse-grained sediments, the Willamette River with its augite-hypersthene assemblage may dominate the present-day heavy mineral assemblage below the point where it discharges into the Columbia.

Although the composition of the heavy mineral suites of the Columbia River Basin and the Klamath-South Coast Basins are similar, the pyroxene/amphibole ratio is 2.3 for the former basin and 0.3 for the latter basins, based on weighted averages. Data summarized by Carlson (1967, table 10, p. 114) showed that sediments associated with the Columbia River generally have a pyroxene/amphibole ratio which lies between 1 and 3.

Heavy Mineralogy of Oregon Beaches

Spigai (1967) examined the heavy mineralogy of 70 different samples of beach sands along the entire Oregon Coast and from these selected five for a preliminary analysis of the heavy mineral suites. The beach sands analyzed were selected for their geographic distribution as well as for diversity of mineral species. Figure 2 shows the locations of the sampling sites and the geographical variation of the relative abundance of the important heavy mineral species.

The sources of the Oregon beach sands are primarily the coastal drainages as well as the elevated marine terraces along the coast. Although the marine terraces now appear to be the major sources of the material for the beaches (Runge, 1966) most of the beach sand no doubt was originally derived from river drainage.

Along the southern Oregon coast, particularly in the vicinity of Cape Sebastian and the Coquille River, the hornblende assemblage of the Klamath-South Coast Basins is evident in the beach sands. The large percentage of blue-green hornblende and actinolite-tremolite, which are characteristic of these basins, is also reflected in the adjacent beaches. The diagnostic mineral glaucophane occurs in the beaches as far north as Yachats in this investigation and Kulm (1965) reported it in the beach sands near the Yaquina River to the north.

The beaches near Yachats have the varied heavy mineral suite similar to that of the Umpqua and Mid-Coast Basins. Pyroxenes and garnet increase at the expense of the amphiboles. Garnet is abundant in these beach sands and probably originates in the Coos, Millicoma, and Siuslaw Rivers to the south.

Farther north along the central Oregon coast the heavy mineral suite shows a marked contrast to the pyroxene assemblage present in the adjacent North Coast Basin. Although pyroxenes, particularly clinopyroxene, dominate the mineral suite of the beaches in the vicinity of Otter Rock and Arch Cape, the sources of the remainder of the suite no doubt are the Columbia River or the drainage basins south of the North Coast Basin, or both.

There is a systematic increase in the percentage of pyroxene and a decrease in amphibole content from the southern Oregon beaches to the northern ones. The percentage of metamorphic minerals, such as blue-greene hornblende, actinolite-tremolite, and epidote, also decrease from south to north. All of these trends and the presence of glaucophane in the beach sands of southern and central Oregon suggest that the predominant direction of sediment transport is from south to north along the Oregon coast.

Conclusions

A preliminary investigation of the heavy mineralogy of the coastal rivers of northern California and Oregon shows that four distinct heavy mineral assemblages can be defined in the continental watershed basins defined by Hagenstein and others (1966): Klamath-South Coast Basins, Umpqua and Mid-Coast Basins, North Coast Basin, and all basins drained by the Columbia River.

The Klamath-South Coast Basins are characterized by a hornblende assemblage which contains abundant blue-green and green hornblende and lesser amounts of actinolite-tremolite. About one-half of the drainages contain the diagnostic mineral glaucophane, which appears to occur only in these basins. Based on weighted averages, the pyroxene/amphibole ratio is 0.3 or the lowest ratio of all basins investigated. Although the bulk of the non-opaque heavy mineral suites of this region consists of minerals derived from both basic and acid igneous sources, it is the metamorphic terrane of the Klamath Mountains that produces this characteristic suite of heavy minerals.

The Umpqua and Mid-Coast Basins display a diverse heavy mineral suite. Umpqua River sediments are dominated by pyroxenes, with abundant hypersthene, and all other amphiboles, except glaucophane, are present but in smaller quantities than in the Klamath and Rogue Rivers. Rivers of the Mid-Coast Basin are also characterized by pyroxenes, but in this case, the clinopyroxenes predominate. In the majority of these smaller drainages large percentages of garnet replace the blue-green hornblende. The sources of the garnet are unknown at this time. Sediment sources for these drainages lie in the northern end of the Klamath Mountains and the southern Oregon Coast Range.

Sediments of the North Coast Basin consist almost entirely of clinopyroxene with only minor amounts of green and brown hornblende and olivine. Titanaugite is a minor but diagnostic constituent in most drainages and originates in the basalt flows and breccias of the central Oregon Coast

Range (Snavely and others, 1965). The bulk of the heavy mineral suite is derived from basic igneous and marine sedimentary rocks of the central and northern Oregon Coast Range.

Limited heavy mineral data for the sediments near the mouth of the Columbia River show that the pyroxenes predominate; the orthopyroxenes, particularly hypersthene, are the most abundant. Hornblende is also common, but neither the blue-green nor the green varieties are as abundant as they are in the Klamath-South Coast Basins. Our data, as well as other investigations of Columbia River sediments, indicate that glacophane is absent in the Columbia. A multitude of rock types occur in the Columbia River Basin and no attempt is made here to identify them, except that it appears that augite and hypersthene-rich sediments are derived from the Cascade Mountains and are carried to the Columbia by the Willamette River.

Each of the four continental watersheds can be defined on the basis of the weighted averages of the pyroxene/amphibole ratios (table 2): Klamath-South Coast Basins, 0.3; Umpqua and Mid-Coast Basins, 3.1; North Coast Basin, 48.0; and Columbia River Basin, 2.3.

The heavy mineral assemblage of the beach sands along the southern Oregon Coast reflects the mineral assemblages of the adjacent drainages, whereas those of the central and northern Oregon Coast exhibit a more diverse mineral suite than occurs in the adjacent drainages. The pyroxene/amphibole ratio is 0.2 near Cape Sebastian off southern Oregon and increases gradually to 2.4 near Arch Cape off northern Oregon. Glaucophane, which apparently occurs only in the southern rivers, is found as far north as the Yaquina River. Heavy mineral data suggest that the predominant direction of littoral drift or sediment transport is south to north along the Oregon coast.

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OCEAN MINING LAW CONFERENCE AGENDA OUTLINED

A tentative agenda for the "Coastal States Conference on a Multiple Use Approach to Ocean Mining Law," to be held at the Portland Hilton Hotel, Portland, Oregon December 11, 12, and 13, 1968 is as follows:

P. M. - Tuesday 10 December 1968

1400 - 2200 - Registration desk open - Lobby, Portland Hilton Hotel.

A. M. - Wednesday 11 December 1968

0800 - Registration desk open.
0900 - Call to order - Kessler R. Cannon, Conference Chairman and Executive Secretary, Governor McCall's Committee on Natural Resources.
Welcome - The Honorable Tom McCall, Governor of Oregon.
0910 - Keynote address - Dr. John Byrne, Head, Department of Oceanography, Oregon State University.
0920 - OSTAC Mining Panel report - RADM. L. D. Coates, USN (Ret.), Lockheed-California Co.
0935 - OSTAC Petroleum Panel report - C. B. Siebenhausen, Shell Oil Co.
0950 - OSTAC Recreation Panel report - H. F. Larson, Outboard Marine.
1005 - OSTAC Fishing Panel report - W. C. Foster, Ralston Purina.
1020 - Question and answer period with OSTAC panel chairmen.
1120 - Survey of problems of ocean mining law:
Operational aspects - C. O. Ensign, Jr., Copper Range Co.
Legal aspects - Wm. L. Griffin, Washington, D.C.
1200 - Luncheon.

P. M. - Wednesday 11 December 1968

1315 - Call to order - Chalmer G. Kirkbride, Conference Co-Chairman, Chairman OSTAC and Vice President (R & E), Sun Oil Co.
1320 - U.S. Department of the Interior - Plans and policies:
Bureau of Commercial Fisheries;
Bureau of Sport Fisheries and Wildlife;
Bureau of Outdoor Recreation;
Geological Survey;
Bureau of Mines;
Water Pollution Control Administration;
Bureau of Land Management.

1515 - Environmental Science Services Admin. - Plans and policies.
1535 - U.S. Coast Guard - Presentation.
1555 - Public Land Law Commission - Presentation.
1615 - Industry presentation.
1645 - Question and answer session with afternoon speakers.
1715 - Recess.

Evening, Wednesday 11 December 1968
1900 - Reception.
2000 - Dinner with honored guests and banquet speaker.

A. M. Thursday 12 December 1968
0830 - Workshops meet as follows:
    Petroleum Panel - Legal advisor, Northcutt Ely;
    Fishing Panel - Legal advisor, David Browning;
    Recreation Panel - Legal advisor, Thomas Clingan;
    Mining Panel - Legal advisor, Wm. Griffin.
1000 - Mining Panel separates to furnish participants to each of the other four workshops.
1200 - Luncheon.

P.M. Thursday 12 December 1968
1300 - Workshops resume.
1530 - General assemble for report of findings of the separate workshops.
1630 - Open conference adjourns.

A. M. Friday 13 December 1968.
0830 - Conference steering group meets to set down findings and recommendations.
1200 - Adjournment.

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APPLICATION OF THE COLEMAN CASE: CONVERSE v. UDALL

"Attempts by proponents of mining claims to limit the effect of the Supreme Court's decision in the Coleman case to claims involving building stone or common variety materials appear to have been squelched by the Ninth Circuit's decision of August 19, 1968, in Converse v. Udall. The court squarely held that a showing that mineral can be extracted, removed and marketed at a profit - the so-called 'marketability test' - is proper to be applied to all mining claims, whether they be for building stone or for precious metals." So writes Justice Department Attorney George R. Hyde in the August 1968 issue of the Land and Natural Resources Division Journal of the Department of Justice. (American Mining Congress Memorandum, Sept. 24, 1968.)

* * * * *

TSUNAMI ON THE OREGON COAST FROM AN EARTHQUAKE NEAR JAPAN

By June G. Pattullo*, Wayne V. Burt*,
and Gerald B. Burdwell**

Just before 3. a.m. on May 16, 1968, tsunami [pronounced "soo-nóm-ee"] waves began arriving on the Oregon coast and were observed on the tide recorder at the Marine Science Center at Newport, Oregon. These waves, commonly called "tidal waves," were generated 10 hours earlier by a strong earthquake off northern Japan. Fortunately, the waves at Newport were not large (about half a foot high), so no serious damage was caused. The tsunami waves reached Crescent City, California, at almost the same time they reached Newport, but the amplitude of the waves at Crescent City was as high as 4 feet. The initial change in water level was a fall at both Newport and Crescent City, whereas most other tide stations around the Pacific Ocean initially experienced a rise in water level.

There were two important results of the May 16th tsunami: (1) The tsunami warning system worked; local authorities had been warned of the coming waves long before they hit the coast, and people in most of the potential danger areas had been evacuated before the waves arrived. (2) Some features of future tsunamis can now be predicted because of the information learned from this small set of waves.

Participation of the Marine Science Center in a warning system, and in regular monitoring of sea level at the coast, affords a new measure of safety and information to Oregon coastal residents. Such local monitoring was lacking in 1964 when a tsunami hit the coast with considerable loss of property and some loss of life. Some results of that tsunami were described in The ORE BIN by Schatz, Curl, and Burt, 1964. These safety measures have been established by cooperation among the Coast and Geodetic Survey of the Environmental Science Services Administration (ESSA), staff of the Oceanography Department of Oregon State University, and ESSA's recently established Weather Bureau Marine Station at the Marine Science Center.

The tsunami warning system was established by the Coast and Geodetic Survey in 1948. The system was based on the use of seismographs to detect and locate earthquakes, and tide gages to detect passing tsunami waves.

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* Dept. of Oceanography, Oregon State University, Corvallis, Oregon.

**ESSA - Weather Bureau, Marine Science Center, Newport, Oregon.

The communications and warning center is at ESSA's magnetic and seismological observatory in Honolulu and it is continuously manned (Coast and Geodetic Survey, 1965).

A "tsunami watch" is issued when seismographs indicate that the location and magnitude of an earthquake are favorable for the generation of a tsunami. A "tsunami warning" is issued whenever the existence of a tsunami has been confirmed, and this confirmation usually comes from tide stations nearest the disturbance. Because tsunamis are of very long wavelength, their velocity is controlled by the depth of the ocean. Thus, arrival times at various points can be predicted once the generating area has been located.

The equation used to compute the speed of the waves is $C = \sqrt{gD}$, where C is the speed of the waves, g is the acceleration of gravity (32 feet per second per second), and D is the depth of the water. For much of the Pacific Ocean the water depth is about 14,000 feet, so the waves travel 670 feet per second or 460 miles per hour. This computed rate is close to the speeds actually observed on 16 May.

Tsunami watches and warnings issued by ESSA's Honolulu Observatory are relayed not only to the United States but also to other participating nations. In the United States, the State Civil Defense organizations are responsible for relaying the warnings to the local population. Although other agencies such as the Weather Bureau, Coast Guard, and police may cooperate in the warning dissemination, Civil Defense has primary responsibility and must establish methods by which warnings and watches are relayed to persons living in danger areas.

Following the earthquake in Japan on May 16, tsunami waves (although low in amplitude) were detected at several Pacific Islands and a

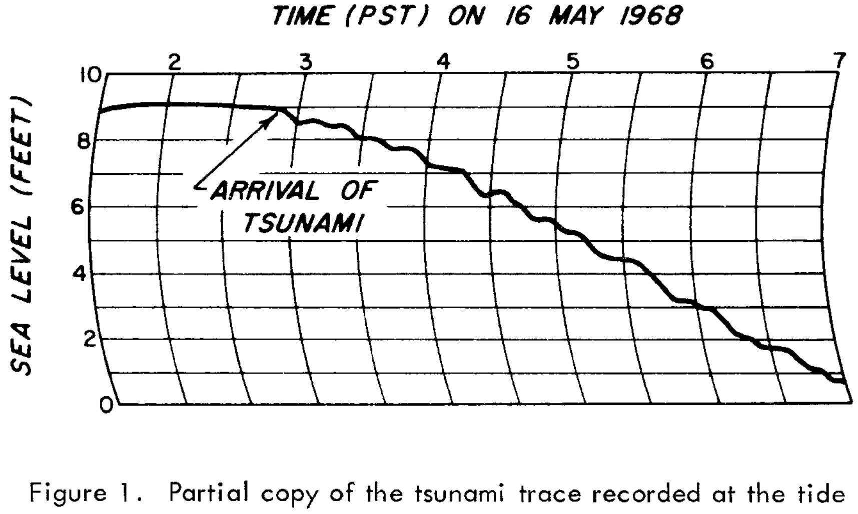

Figure 1. Partial copy of the tsunami trace recorded at the tide gage at Newport, Oregon. Sea level is measured from average height of the lower of the two low waters every day.

tsunami warning was issued. The waves at Newport continued for about two days, from 2:50 a.m., PST, 16 May, until about 5:00 a.m., PST, 18 May. This is a commonly observed feature in tsunamis; the waves in the harbors last much longer than the earthquakes that caused them. The waves varied both in period (time between successive maximum heights) and height (elevation between high and low levels) (see fig. 1). On the average there were 3-1/3 peaks or high waters per hour, or an average interval of about 18 minutes between successive high waters.

Detailed examination of this set of records will make possible better predictions of future tsunami waves in this region. It has been found that each harbor has its own way of reacting to tsunamis (Miller, 1964). Once a harbor's response has been measured and described, the response can be used to help predict the wavelengths of future tsunami waves. For example, we can probably expect some waves of periods near 16 to 20 minutes whenever we have a tsunami near Newport. However, the details are complicated. Data from this tsunami and others, as they occur in the future must be compared with everyday records collected in the bay. Some studies have been begun (for example, Gilbert, 1967).

Additional research will continue to improve the accuracy and increase the scope of tsunami warnings. At present, only arrival time can be estimated accurately; no reliable system is available for prediction of wave height and other characteristics. An improved understanding of tsunamis and their generation, propagation, and response to different shorelines will permit more comprehensive warnings -- and help save lives when the great waves strike.

Acknowledgment

This work has been supported in part by Office of Naval Research Contract number Nonr 1286(10).

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AVAILABLE PUBLICATIONS

(Please include remittance with order. Postage free. All sales are final and no material is returnable. Upon request, a complete list of the Department's publications, including those no longer in print, will be mailed.)

BULLETINS

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26.	Soil: Its origin, destruction, preservation, 1944: Twenhofel	0.45
33.	Bibliography (1st supplement) of geology and mineral resources of Oregon, 1947: Allen	1.00
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	(2nd vol.) Two papers on Western Oregon and Washington Tertiary foraminifera, 1949: Cushman, Stewart, and Stewart; and one paper on mollusca and microfauna, Wildcat coast section, Humboldt County, Calif., 1949: Stewart and Stewart	1.25
37.	Geology of the Albany quadrangle, Oregon, 1953: Allison	0.75
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